Spatio-temporal variability of global remotely sensed soil moisture products

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Introduction

For progress in hydrological and climate modeling and for numerical weather prediction, information about the spatio-temporal dynamics of soil moisture is crucial. Moreover, up- and downscaling of remotely sensed soil moisture products as well as data assimilation require knowledge about the distribution of soil moisture.

This study examines spatial and temporal variability of 3-day-composites of SMOS-, ASCAT- and ERA Interim soil moisture products for the years 2010 and 2011 for the American continent and compares their patterns based on USDA soil orders. Factors influencing the soil moisture distribution are analyzed.

Data

SMOS (Soil moisture and ocean salinity)
- Volumetric soil water content [m³/m³]
- SMOS Level 2 Processor Version 5.01

ASCAT (Advanced scatterometer)
- Relative soil moisture [%]
- SOMO version 2.0 (from 18/08/2011: version 3.1)

ERA Interim
- Model reanalysis from ECMWF
- Volumetric soil water content [m³/m³]
- Layer 1: 0-5 cm

USDA soil distribution

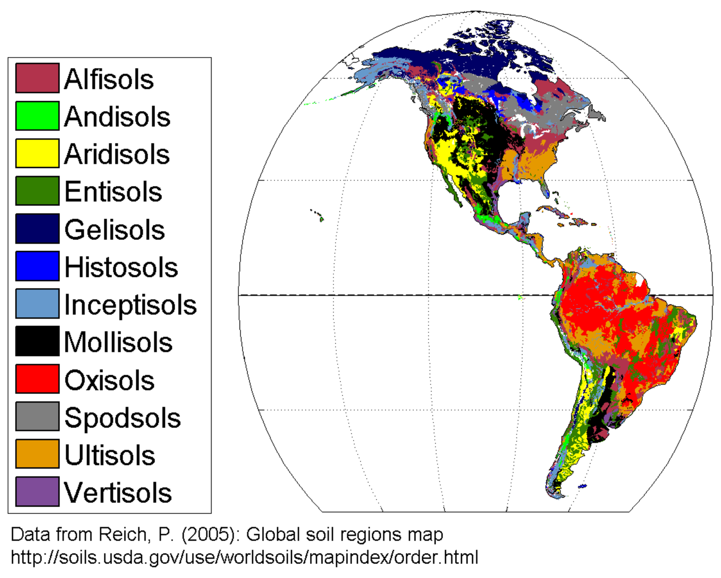

Fig. 1: Distribution of USDA soil orders for the American Continent

Mean relative differences (MRD)

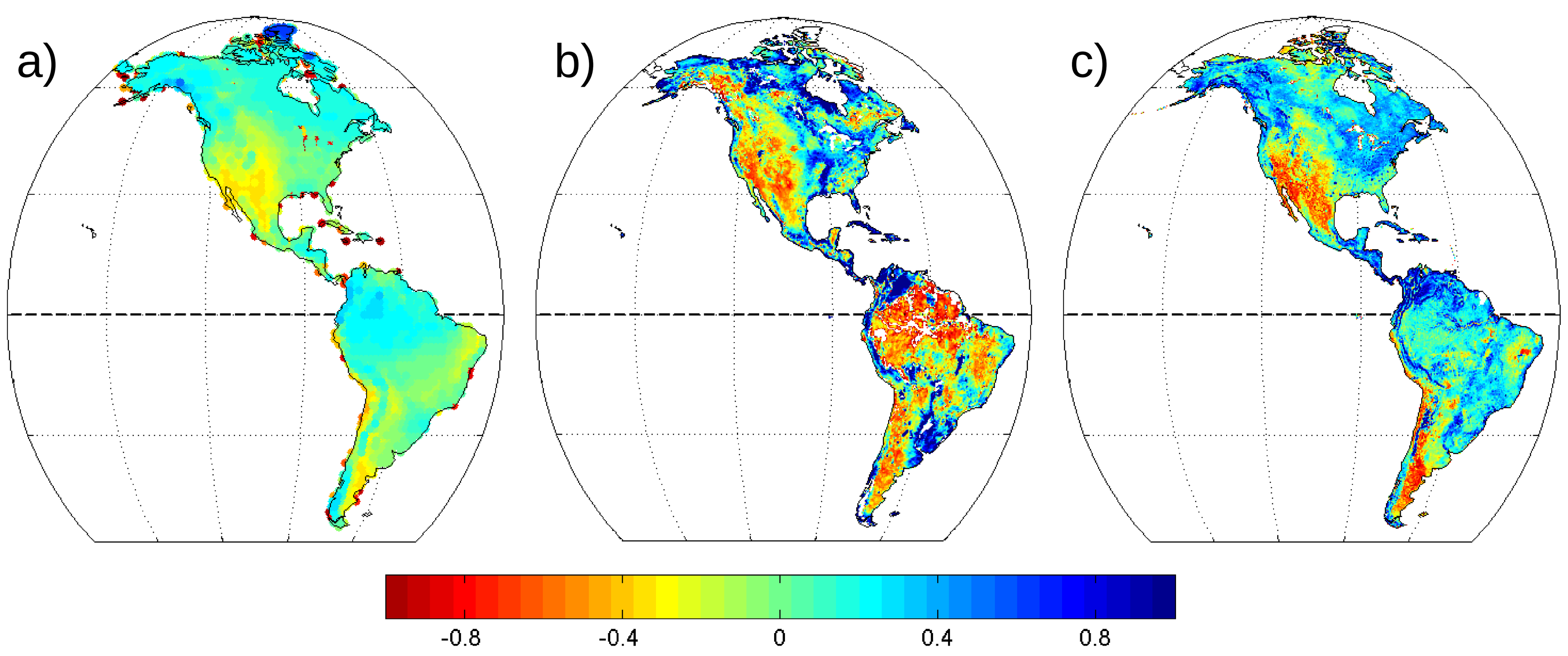

Fig. 2: Spatial distribution of mean relative differences for a) ERA, b) SMOS and c) ASCAT. Negative MRDs for SMOS in the tropics imply difficulties in retrieving soil moisture under dense vegetation, differences in the north may be due to Permafrost. ERA exhibits a small range of MRDs but a similar distribution as ASCAT.

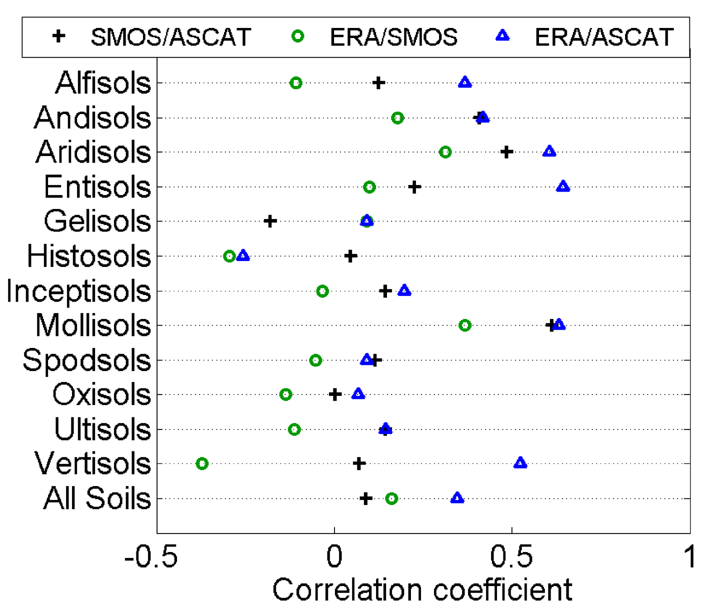

Fig. 3: Correlation of ranks of the three products. High positive correlations indicate similar soil moisture distribution and thereby reliable soil moisture data for the respective soil order. Low correlations indicate poor quality for at least one of the soil moisture products.

Methods

- Analysis of spatio-temporal soil moisture variations through the relation between spatial mean ($\overline{\theta}_n$) and spatial variance (σ_n^2) of every soil moisture value θ_{nt} for pixel n at time t

$$\overline{\theta}_n = \frac{1}{N}\sum_{n=1}^{N}\theta_{nt} \quad (1) \qquad \text{and} \qquad \sigma_n^2 = \frac{1}{N}\sum_{n=1}^{N}\left(\theta_{nt} - \overline{\theta}_n\right)^2 \quad (2)$$

- Soil moisture values are split up into temporal mean ($\overline{\theta}_t$) and anomalies (A_{nt}) following the approach of Mittelbach et al. (2012)

$$\theta_{nt} = \overline{\theta}_t + A_{nt} \quad (3) \qquad \text{with} \qquad \overline{\theta}_t = \frac{1}{T}\sum_{t=1}^{T}\theta_{nt} \quad (4)$$

- Accordingly, spatial variance was described as

$$\sigma_n^2 = \sigma_n^2(\overline{\theta}_t) + 2cov(\overline{\theta}_t A_{nt}) + \sigma_n^2(A_{nt}) \quad (5)$$

where $\sigma_n^2(\overline{\theta}_t)$ is the time-invariant spatial variance of temporal mean soil moisture, and $cov(\overline{\theta}_t A_{nt})$ and $\sigma_n^2(A_{nt})$ are the time-variant covariance between spatial mean and anomalies and spatial variance of anomalies, respectively

- Mean relative difference ($\overline{\delta}_t$,MRD) is calculated for every pixel through

$$\overline{\delta}_t = \frac{1}{T}\sum_{t=1}^{T}\frac{\theta_{nt} - \overline{\theta}_n}{\overline{\theta}_n} \quad (6)$$

Spatial mean and variance

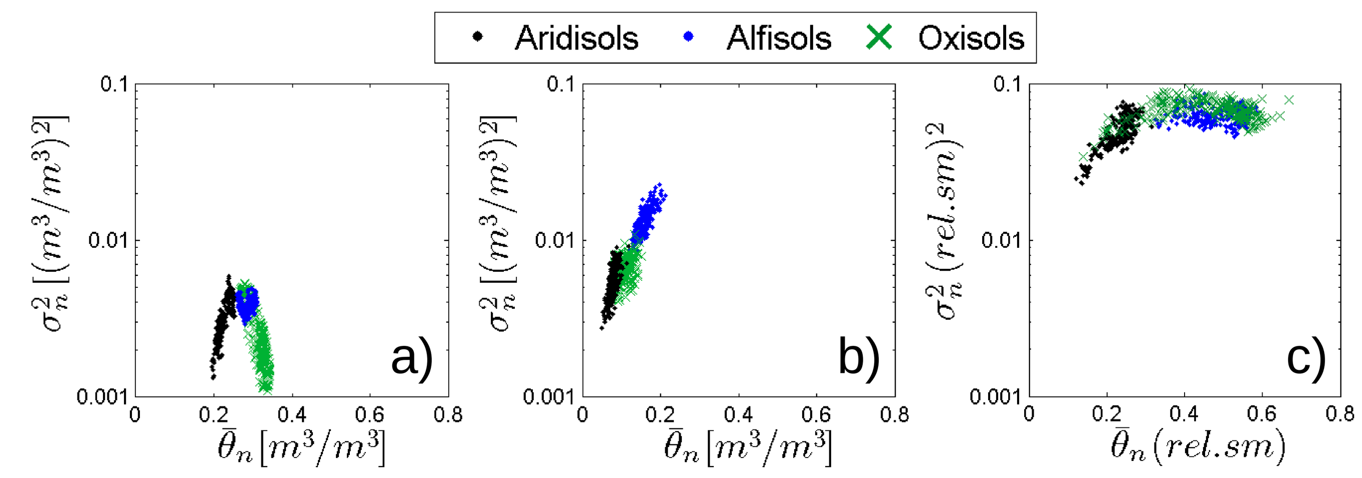

Fig. 4: Relation between spatial mean and spatial variance of soil moisture for a) ERA, b) SMOS and c) ASCAT soil moisture for selected soil orders. Different relationships of the products reflect characteristics of the products, while the same relationships (e.g. Aridisols) indicate characteristics of the respective region.

Temporal mean and anomalies

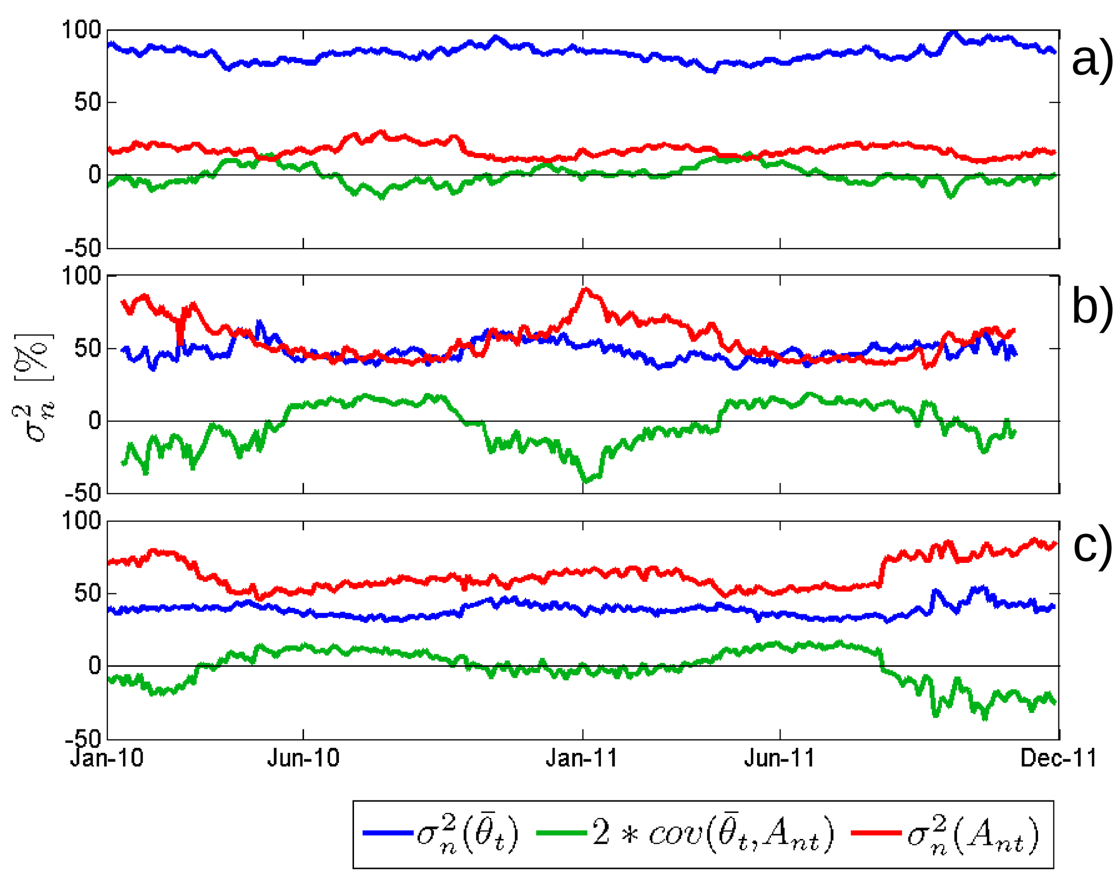

Fig. 5: Time series of percentages of the single contributors to spatial variance for a) ERA, b) SMOS and c) ASCAT. High contribution of the variance of anomalies to spatial variance shows, that in the remotely sensed products not only climate influences the spatial variance of soil moisture, but also temporal variant factors, for example seasonal changes, while for the modeled ERA product, the time-invariant factors have high influence.

Conclusions

- The analysis of the spatio-temporal variability of soil moisture is a proper tool for comparing different soil moisture products, even if they have different units
- The splitting of spatial variance into its time-variant and time-invariant contributions gives information about the factors influencing spatial and temporal soil moisture patterns, like seasonal meteorological changes or climate regions
- The three products show, with some exceptions, similar spatial patterns of soil moisture
- While SMOS shows positive correlations between spatial mean and spatial variance, ASCAT and ERA Interim exhibit different relationships for different soil orders
- The splitting of spatial variance shows that in the remotely sensed products time-variant factors like seasonal changes have high influence on spatial variance, while the time-invariant factors dominate in the ERA Interim soil moisture product

Reference

H. Mittelbach and S.I. Seneviratne (2012): A new perspective on the spatio-temporal variability of soil moisture: temporal dynamics versus time-invariant contributions. Hydrol. Earth Syst. Sci., 16, 2169-2179

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